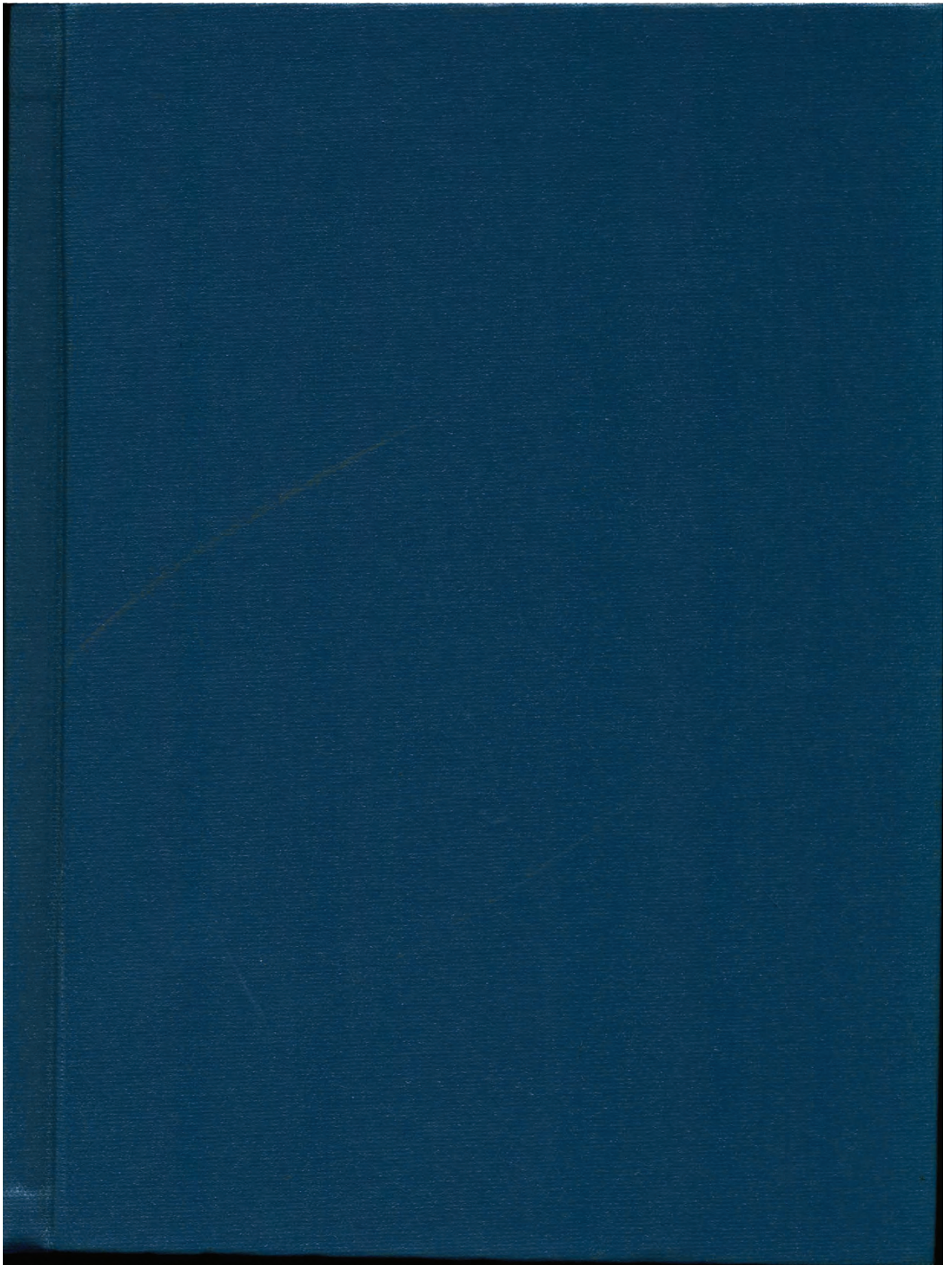




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1995 PROCEEDINGS

45th ELECTRONIC COMPONENTS & TECHNOLOGY CONFERENCE May 21 - May 24, 1995 *Las Vegas, Nevada*

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Assembly of a Prototype Flip-Chip-On-Glass Liquid Crystal Display

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Abstract --- The authors will discuss the stages of development and assembly of a prototype Flip-Chip-On-Glass (FCOG) liquid crystal display. The driver IC's were mechanically bonded and electrically interconnected using anisotropically conductive adhesive (ACA).

In the first phase, test panels were assembled using an ultraviolet (UV) curable ACA. Without the benefit of the self-alignment properties of solder, a high precision pick-and-place machine was used. A modified MCM/Hybrid die attach system was successfully used. Properties of the material will be offered along with the necessary process steps and conditions. The panels were subject to reliability tests. Results of these tests will be offered. In the second phase, glass panels for the a prototype display and bumped driver IC's were prepared. Design considerations will be discussed. The assembly of the prototype display required a machine capable of handling a large area panel and capable of radiation processing. A new flip chip bonder was designed and built to the necessary specifications. Other key requirements for the bonder were placement accuracy and force.

In the assembly of the displays, process difficulties were encountered and overcome. Some of these experiences will be shared. Suggestions for future enhancement to materials, equipment, and process will be offered.

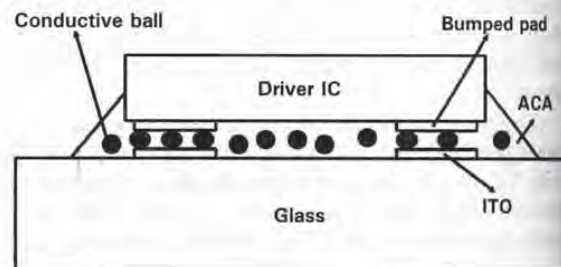
BACKGROUND

Liquid Crystal Displays (LCD's) use thin transparent indium tin oxide (ITO) traces as the medium for interconnect. These ITO traces allow for electrical connections to the liquid crystal without obscuring the display segment. In order to maintain the integrity of ITO traces, low-temperature non-solder packaging techniques are required. In the early days, ITO traces were connected to the driver circuits through elastomeric connectors, or zebra strips. Heat seal connector, a

suspension of graphite particles in a thermoplastic adhesive matrix, was developed to address the needs for higher I/O count and finer pitch. Now, with help from advances in wafer fabrication, driver circuits are integrated into chips, called driver IC's. The trend for down-sizing and the push for lighter weight displays called for driver IC's to be located at the extremities of the display. TAB-on-glass using ACA's was developed.^[1] Driver IC's are inner lead bonded (ILB) to the tape carrier. The outer leads of the tape are then outer lead bonded (OLB) to the ITO's on the glass panel through Anisotropically Conductive Film (ACF). Pitches as small as 70 microns can be achieved.

However TAB has a mechanical limitations in achieving pitches of 50 microns or less. With increasing needs for higher resolution displays, higher density interconnect technology becomes inevitable. Direct mounting of flip chip onto glass using ACA's (see Figure 1) became the topic of investigation for many Japanese and Korean LCD manufacturers and for Government sponsored programs.

Figure 1



Interconnection with ACA

This paper reviews the first two phases of a series of feasibility studies carried out by three companies: Samsung, Zymet, and Micro Robotics Systems, Inc.. Studies were focused on UV curable ACA. The objective was to search for a reliable and manufacturable FCOG process. Similar to Multi-Chip-Module (MCM) technology, major concerns on the availability of Known Good Die (KGD) and on reworkability needed to be carefully addressed, especially in cases of multiple driver IC's per display. These two issues will be addressed toward the end of this paper.

SUBSTRATES AND CHIPS

Information on the chips and glass substrates used during these two phases of experiments are summarized in Table 1 and Table 2. Although the target applications are for pitches of 50 microns or less, parts with larger pitch dimensions were used so that other issues could be studied and addressed first.

During the first phase of experiments, the bumps were made of Electroless Nickel. It presented a tighter coplanarity requirement to the process equipment due to its hardness. Gold plated bumps were used during the second phase of experiments. There was only one driver IC per glass test board in the first phase. During the second phase, there were four column and three row driver IC's bonded to the same prototype display.

Table 1

Driver IC's and Glass Test Substrates
for First Phase of Experiments

Driver IC	
Part Number	KS0066
Die Size, mm	3.97 x 4.55
Number of I/O's	80
Bump Material	Electroless Nickel
Bump Height, microns	10
Bump Size, microns	120 x 120
Pitch, microns	180
Glass Test Substrate	
Glass	Sodalime
Size, mm	30 x 30 x 1.1
Conductive Traces	ITO

ADHESIVE

Anisotropically Conductive Adhesives consist of two major components : Conductive particles and adhesive. Conductive particles provide conduction in the Z-axis only, when they are pressed, along the Z-axis, between two opposing conductors. The adhesive maintains a mechanical bond between the die and the substrate after it is cured using heat or UV radiation.

There are two types of heat-cured adhesives : thermoset and thermoplastic. Introduction of heat into the thermoset adhesive causes the formation of three-dimensional chemical

Table 2

Driver IC's and Prototype Displays
for Second Phase of Experiments

Driver IC	Column	Row
Part Number	KS0786	KS0789
Die Size, mm	13.36 x 1.45	13.90 x 1.36
Number of I/O's	80	100
Bump Material	Gold	Gold
Bump Height, microns	20	20
Bump Size, microns	100 x 100	100 x 100
Pitch, microns	160	130
Prototype Display		
Glass	Sodalime	
Size	8 inches diagonal	
Type	320 x 240 B/W F-STN LCD	
Dot Pitch	0.5mm	
Conductive Traces	Chrome on ITO	

bonds that "set" the adhesive permanently. Therefore, using thermoset adhesive involves a more tedious rework procedure, such as twisting the die from the substrate with brutal force. Thermoplastic adhesive, on the other hand, gets soft when it is heated. This allows for easier rework procedures than thermoset adhesives.

UV curable adhesive is set by absorbing UV energy. Its chemical structure is similar to that of thermoset adhesive. Hence, once it is cured, re-softening is not possible. Rework with fully cured UV curable adhesive involves removing the die with large force. A better rework strategy when working with UV curable adhesive was identified and will be discussed later.

Conductive fillers typically have a plastic core, spherical in shape, with metal coating on the outside surface. The conductive balls deform under force. This compliant nature plays an important role in ensuring proper electrical interconnections: by compensating for non-coplanarity between bond pads on die and on substrate, and by compensating for non-uniformity in diameter among conductive balls. Conductive balls as small as 5 microns in diameter are available.

The *particle loading* is defined as the percentage of conductive balls in the adhesive by volume. The required particle loading is calculated based on pitch, pad size and target particle count per pad after die mounting.^[2,3] Lateral conduction caused by over-crowded particles should also be considered and avoided. The force needed during bonding is directly proportional to the number of conductive balls sandwiched between pads.

ACA's are typically available in either film or paste form. Anisotropically Conductive Film (ACF) is typically sold with a protective cover on one or both sides of the film. Peeling off

the protective cover(s) and cutting the film are part of the ACF application process. For LCD panels using slim TAB, a long strip of ACF is tacked to the glass panel using heat prior to mounting the die. For flip chip on glass, it is possible to die cut ACF onto the glass panel.

Paste, on the other hand, needs a different application method. Screen printing and stenciling are two prime candidates for paste application. Stamping adhesive to the bond site and dipping the chip into an adhesive-well are two other possibilities. But further evaluations are needed to make sure that the process will not agitate adhesives. There is a unique opportunity for using UV curable ACA in flat panel display applications, because it is possible to cure the adhesive through the glass panel.

Experiments reviewed in this paper were based on Zymet's UV curable ACA in paste form. Conductive particles were 7 microns in diameter. Some other properties of this material are summarized in Table 3. The paste application method used was stenciling, with adhesive thickness of 25 microns. The adhesive was stenciled onto the die sites on the glass panels. The shape of the stencil was designed so that bond pads at corners of die sites were left uncovered by the paste for alignment purposes.

Table 3

Properties of Zymet's UV Curable ACA

Adhesive Type	UV Curable
Cure Condition	15 seconds
Force During Cure, Kg	1*
Glass transition Temperature, °C	135
CTE, ppm/°C	
Below Tg	32
Above Tg	118
Particle Size, microns	7
Particle Loading, vol.%	5

* Force applied to KS0066 driver IC's.
Required force will vary with IC design.

ALIGNMENT METHODOLOGIES

Various methods have been implemented by equipment vendors to provide capabilities in aligning chips to substrates, including flip chip bonding. In general, they can be divided into two categories : active and passive alignment methodologies.^[4,5,6]

Active Alignment

The basic concept of active alignment is to bring the component close to the target so that the component and the target can be processed in the same picture, or field-of-view, for further X, Y and θ corrections. The major benefit of this methodology is that one can anticipate final placement accuracy before placing the component. For most high

precision placement applications, one field-of-view usually cannot render enough optical resolution to support the needed alignment accuracy. Hence, multiple fields-of-view must be considered. Approaches such as multiple optics, split-field-optics and moving the optics to view multiple areas are some ways to achieve multiple fields-of-view. Not all alignment problems can adopt this methodology, because obtaining a composite picture of both the component and the target may not be possible. TAB and FCOG are two of prime candidates for using active alignment.

Passive Alignment

In contrast to active alignment, passive alignment normally involves a set of pre-calibration procedures that establish geometrical relationships among system devices : the vision system(s), the pick-and-place head, θ -center, etc. All subsequent operations use these calibration results, which is why this methodology is also called the pre-calibrated alignment technique. Both inaccuracy in calibration and system structural instability contribute to the final placement error. Unlike active alignment, the final placement accuracy of passive alignment cannot be measured prior to placements. Most robotic workcells, including machines for surface mount technology (SMT), use this alignment methodology because of it is easy to implement and has a less complicated image to process. It typically provides higher throughput, since parallel mechanical motions are possible.

FIRST PHASE EXPERIMENT

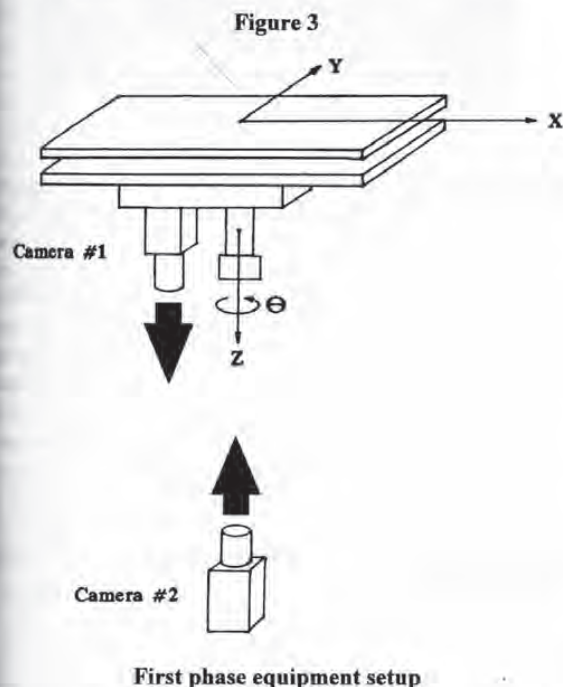
The first phase of experiments was conducted on a modified MRSI-505: a High Precision Die Attach System (see Figure 2).

Figure 2



First Phase Equipment

This system follows the methodology of passive alignment. A four axis robot is the heart of the system. Three axis move in the Cartesian coordinates system, : X ,Y and Z, and a fourth axis provides θ rotation of the pick and place head, as depicted in Figure 3. Two vision systems are integrated in the system. The first vision system is mounted on the robot arm and is looking downward. The purpose of it is to locate alignment features on glass panels. The second vision system is fixed to the system frame, and is looking upward for aligning flip chips. The relative positions of the vision systems and the placement head were determined by going through system calibration procedures.



Integrated into the pick and place head is a flexure type of strain gauge that controls and monitors the final placement force. At the time experiments were conducted, the maximum force was set at 1 Kg. A UV light source was mounted directly underneath the glass panel for curing the adhesive right after placement. In our experiments, glass panels were presented to the system manually. Driver chips were presented through wafflepacks, with chips pre-flipped. The placement accuracy of the system was 12 μ m.

The automatic operation cycle consists of :

1. The robot moves the first vision system to several pre-programmed positions on top of the glass panel to determine the placement target.
2. The robot picks up one chip from the wafflepack with bumps facing downward.
3. The robot presents the chip to the second vision system, which determines the chip's XY location and orientation.
4. The robot make appropriate adjustments in θ , and moves the chip to the target in X and Y.
5. The robot moves the chip downward to the target chip site. Meanwhile, the host computer is comparing the strain gauge reading against the programmed target force. Once the final force is reached, the robot stops its motion.
6. The UV light source is turned on to cure the adhesive.
7. The robot releases the chip.

Findings

During the experiments, a visual inspection technique was developed to differentiate between good and bad bonds. After bonding, conductive balls can be observed through the back side of the panel. For a good bond, there is a single layer of conductive balls spread between the bond pads of the chip and the glass panel. Conductive balls are pressed and deformed such that they are flattened on two sides. Using a microscope with co-axial illumination to view through the glass, light gets reflected back to the eye pieces wherever there is a flattened surface on the ball. This technique provided quick and useful feedback throughout the experiment.

Several important factors that affect the quality of the bond were identified :

1. Co-planarity

Coplanarity between the chip and the glass panel contributes significantly to placement accuracy. As the aligned chip maneuvers downward to contact the glass panel, non-coplanarity causes one corner contact first, resulting in a lateral kick. Non-coplanarity will also create opens, as the amount of non-coplanarity exceeds the compliance of the electrically conductive balls in the adhesive. During the first phase experiment, co-planarity adjustment was achieved by leveling the fixture for the glass panel. The requirement for co-planarity was determined to be 1 μ m over 4.55 mm, or 0.8 arc minute. It was difficult to meet this requirement through mechanical means. Trial and error helped us in setting up the system correctly.

2. Placement force control

A flexure type of strain gauge is an integral part of the pick and place head design. It provides compliance to the head, as well as force control. Compliance is needed to insure soft initial contact during pick and place operations. A high final force is essential to ensure the proper final contact resistance between the chip and glass panel. During the first phase of experiments, the maximum force the head could deliver was 1 Kg, which was marginal according to the theoretical calculations. Throughout the first phase of experiments, 1 Kg force was used.

3. UV exposure time

The exposure time required to fully cure the adhesive is a function of :

- The chemical properties of the adhesive
- The power of the UV light source
- The transmission media used from the UV lamp to the glass panel
- The distance from the end of the transmission media to the glass

The desired exposure time to fully cure the adhesive was determined to be 15 seconds using a EFOS 100SS light source, which delivers 1.5 Watt/cm^2 of light centered at 365nm. Concern was raised that long exposure time would greatly impact the production throughput. A set of experiments was designed and carried out to investigate a two-step curing process. The first step is to tack the chip to the glass panel by partially curing the adhesive. At this time, the adhesive was only gelled, but it was still strong enough to hold the driver IC in place for electrical testing. The second step is a simple off-line cure (post-cure) without applying force to the driver IC's. The results were successful. The tacking time needed was less than 5 seconds, which was quite a significant improvement. Another possible way to speed up adhesive curing time was to use a heated collet. Due to system and time limitations, no actual experiments were carried out.

Reliability Test Results

Standard LCD reliability tests were applied to all first phase samples. Conditions of these tests are summarized in Table 4.

Table 4

First Phase Reliability Test Conditions

Test	Conditions
High Temperature Storage	80°C, 500 Hours
Low Temperature Storage	-30°C, 500 Hours
Moisture Resistance	80°C, 90% RH, 500 Hours
Thermal Cycle	-35°C 35 min. $\Rightarrow$ 25°C 5 min. $\Rightarrow$ 80°C 35 min. 180 Cycles

Samples were pull out of testers, at 50 hours (35 cycles), 150 hours (120 cycles), 300 hours (180 cycles) and at the end of the 500 hours, for electrical testing. All samples passed above reliability tests at all check points.

SECOND PHASE EXPERIMENT

The second phase of experiments was conducted on a new piece of equipment, the MRSI-503S-TC (see figure 4), which was designed specifically to address issues identified during the first phase of experiments. This system follows the methodology of active alignment, in which alignment is performed with the chip close to the glass panel. An optical device that provides both up and down viewing is the heart of this system. This optics are positioned between the flip chip and glass panel during alignment (see Figure 5). Images of the chip and the glass panel are obtained by activating the

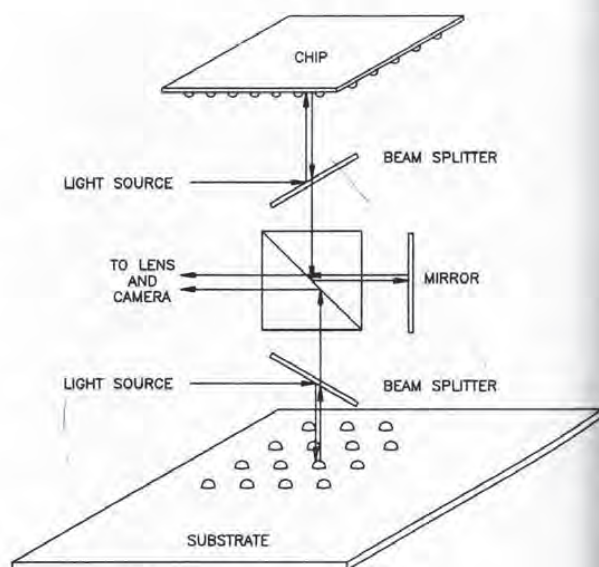
Figure 4



Second Phase Equipment

appropriate light sources. Adjustments are incorporated into the tip, the glass panel table and the optics. On the tip, the degrees of freedom are X, Y, θ and Z. The X, Y and θ are used in alignment, whereas Z is used in focusing and placement. On the glass panel table, the degrees of freedom are X, Y, pitch and yaw. X and Y are for alignment. Pitch and yaw are for co-planarity adjustments. The optical device has one degree of freedom : Y. The optical magnification is about 150X. It was purposely kept high so as to support high accuracy alignment. The mechanisms were carefully designed to minimize the number of steps in the alignment procedure. The θ mechanism on the tip is on top of the X and Y mechanism, and its center of rotation is pre-calibrated relative to the optics. The alignment procedures are as follows : (also refer to Figure 6)

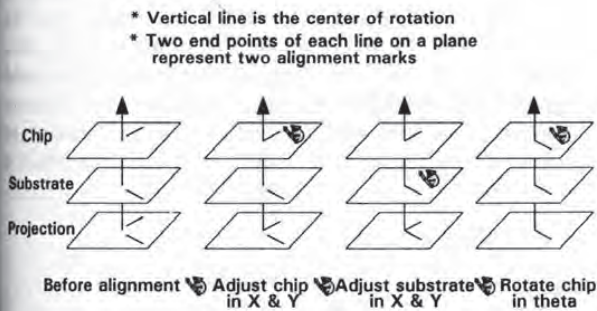
Figure 5



Second Phase Equipment Setup

1. Pick up a chip and slide the optics to the first alignment position.
2. Adjust the chip in XY so that the first alignment mark coincides with the center of rotation.
3. Adjust the glass panel in X and Y so that the first alignment mark coincides with the center of rotation.
4. Move the optics to the second alignment position.
5. Mark the second alignment marks of the glass panel with the video micrometer.
6. Rotate the chip in theta so that its second alignment mark is matched with video micrometer.

Figure 6



Second Phase Equipment Alignment Procedure

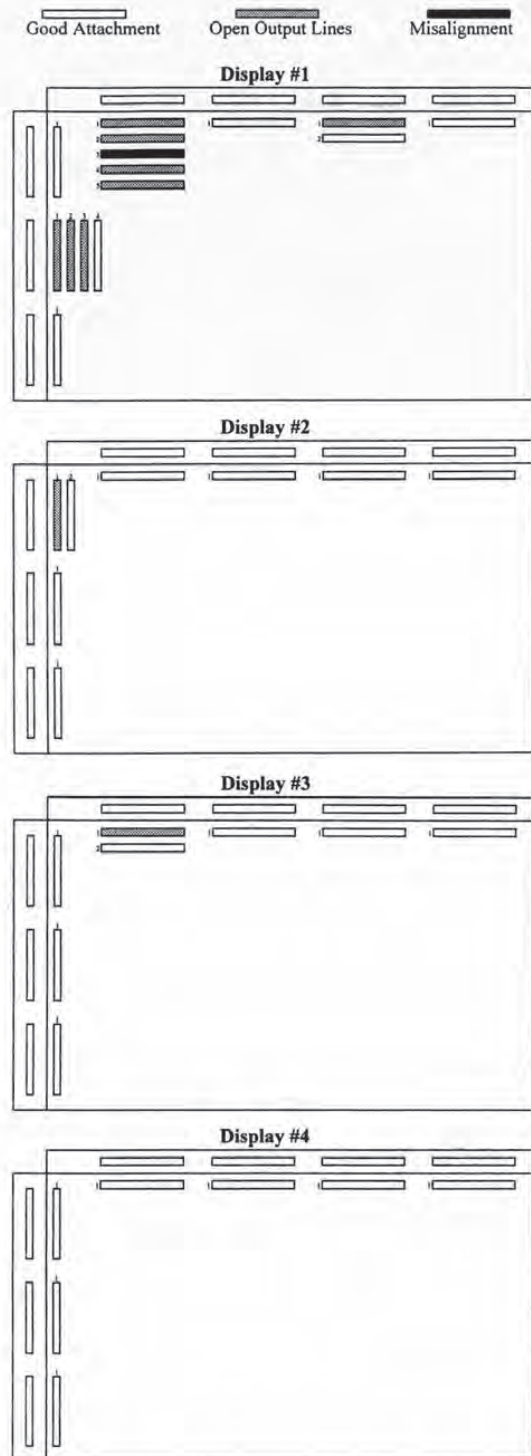
After the two pieces are aligned, push the optics out of the way and initiate the bonding process. The bonding process is automatic : the Z-axis comes down with the chip, the computer monitors the strain gauge reading, and once the target force is reached, Z-motion stops. With the force still on, the UV light source is turned on to tack the adhesive. At this time, the adhesive will be only partially cured so that it has enough strength to hold the chip in place.

This system can provide up to 30 Kg of force, more than adequate for Flip-Chip-On-Glass applications. It also has a heated collet mounted for speeding up adhesive curing time.

Results

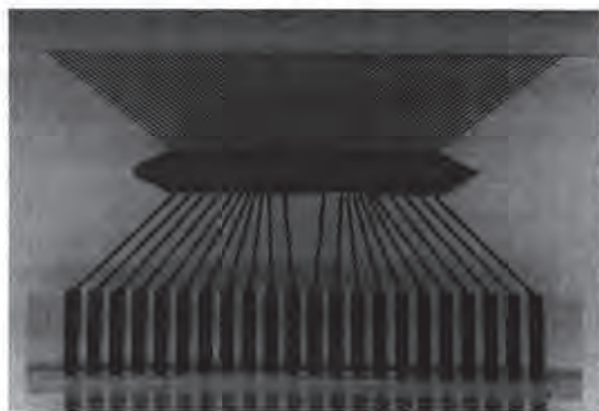
Four displays were successfully assembled. The assembly records of each display are shown in Figure 7. On the first display, several driver IC attachments had to be repaired multiple times. Adjustments to coplanarity had to be made and other alignment problems had to be accounted for. As these adjustments were made, the need for repair was greatly reduced. The second and third panels required repair of one driver IC each, due to a few electrically open lines. There were no failures caused by electrical shorting. The fourth display required no repair at all. Figure 8 presents a close up of an attached driver IC on an operating display.

Figure 7



Second Phase Assembly Records

Figure 8



Flip-Chip-On-Glass Sample Close-up

DISCUSSIONS

Bond pad layout

The trend for flat panel displays is that the total number of connections will keep increasing, requiring finer pitches for interconnection. Conventional bond pads are laid out in a linear fashion. The size of the bond pads is typically larger than the spacing between bond pads so as to maximize the effective bond area in case of mis-alignment. However this also means that the allowance for mis-alignment is minimized. As a result, high accuracy machinery is required, which costs more to build, and naturally, requires more maintenance. For applications using Anisotropic Conductive Adhesive, it is possible to stagger the bond pads to relieve the accuracy requirement.

Autocollimator

Co-planarity is one of the important factors in building flat panels displays successfully using Anisotropic Conductive Adhesive. At the time of first and second phase experiments, trial and error was the method used in adjusting co-planarity. After the second phase, an optical device called an *autocollimator* was designed, fabricated and tested. This autocollimator provides guidance for co-planarity adjustment by visually displaying pitch and yaw mis-matches between chip and glass panel. It should be noted that this autocollimator is needed only when setting up the system.

Active Alignment

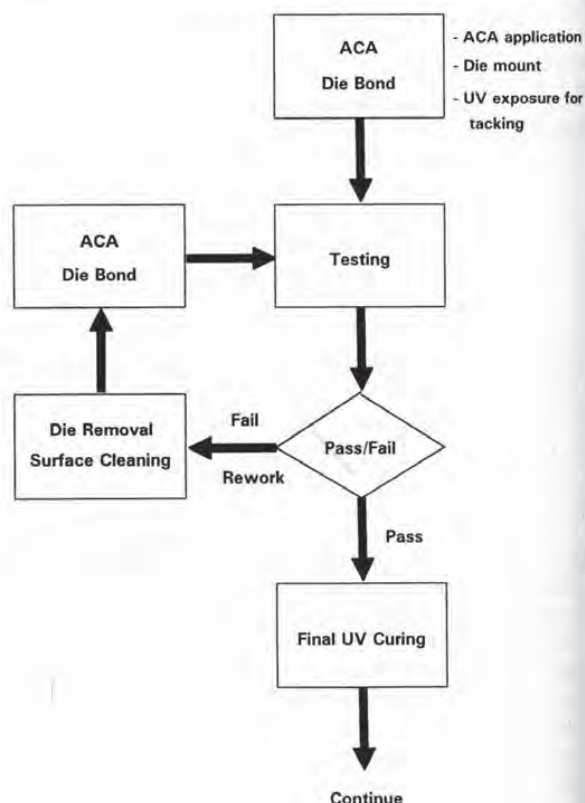
The equipment used during second phase of experiments was a general purpose flip chip bonder. Although it was adequate to do the job, it is not the ultimate system for the flat panel display industry. The ultimate machine should use the true active alignment methodology : keeping chip and glass panel as close as possible during alignment. The MRSI-503S-TC can be readily modified by re-mounting the optics underneath

the glass panel. The optics would look through the glass to see the ITO's on the top surface of the glass, while the chip is just above the glass. As a result, the alignment patterns from both the chip and the glass panel would be visible simultaneously. This method would eliminate the importance of system calibration, making the system easier to maintain.

Reworkability

Because of the two-step UV curing process, driver IC's can be easily removed, and the glass surface can be easily cleaned. This is a reworkable process. The purpose of functional testing in the proposed process is two-fold: (1) to validate the die mounting process, and (2) to test the driver IC's. The availability of known-good-die is still one of the major issues being worked on by chip suppliers. Meanwhile, any substrate that contains multiple chips must be concerned with the implications of running a process without known-good-die. The fact that functional testing can also be considered as confirmation of the driver IC's integrity is a crucial factor for LCD manufacturers to evaluate.

Proposed UV Curable ACA Process Flow Chart



CONCLUSION

The developmental efforts described in this paper were successful. A reworkable flip-chip-on-glass process using UV curable ACA paste was successfully developed and verified. The major advantages are reworkability, a short system cycle time, and relief from the burden in obtaining known-good-die. Future enhancements to the equipment and the process were proposed, and some of them have already been implemented. Although studies were based on ACA in paste form, the same technology could easily be adopted to ACA's supplied in film form.

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